Section 4

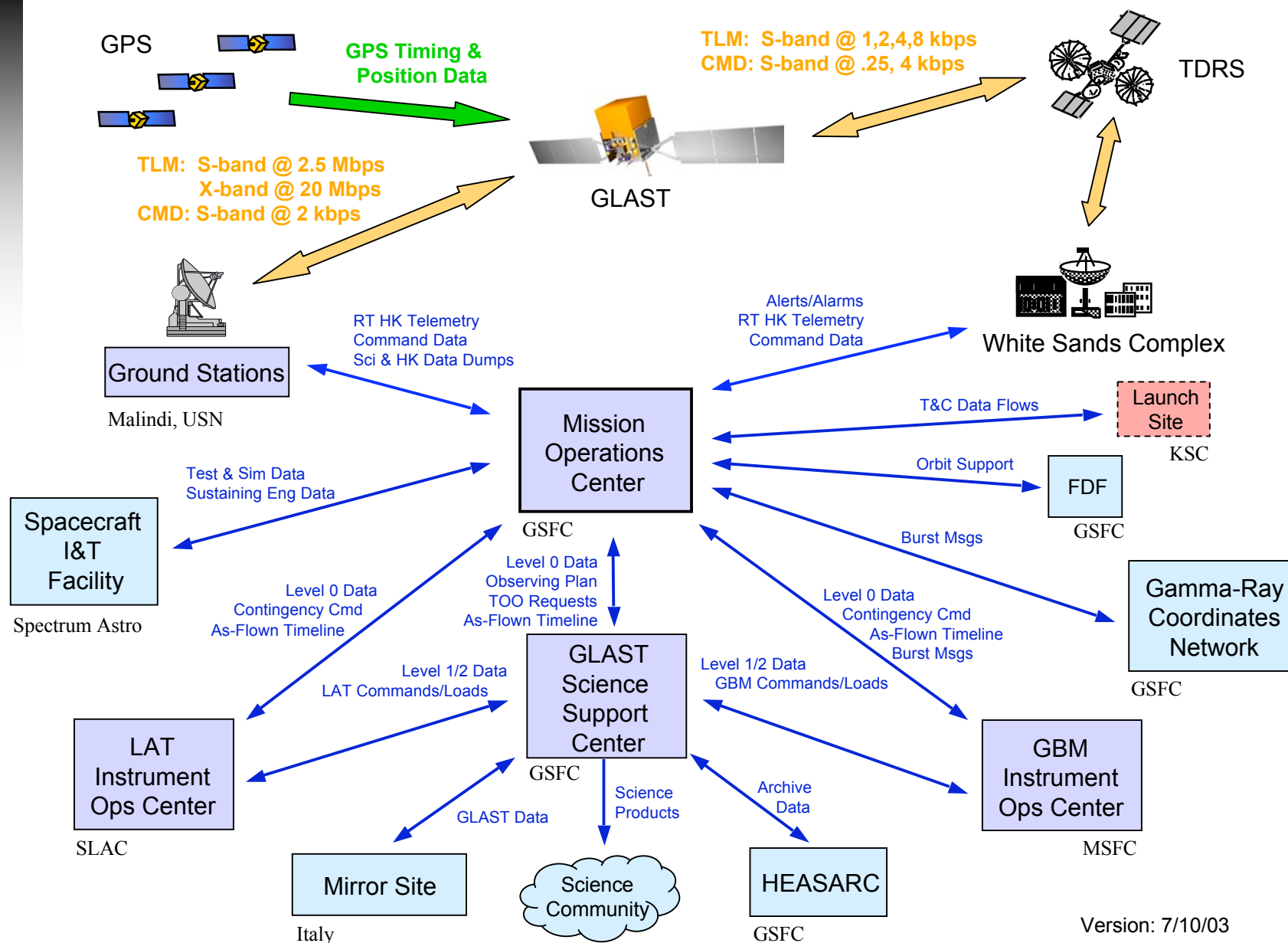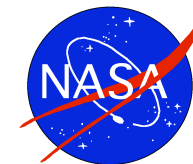## Operations Concept/Scenario

John Nagy
FOT Lead

Outline

- ▶ *Ground System Architecture*

- ▶ *Operations Overview*

  - – *Week in the Life of GLAST*

- ▶ *Mission Planning and Command Generation*

- ▶ *Ground Station and TDRSS Scheduling*

- ▶ *Telemetry and Command*

  - – *Real-time telemetry*

  - – *Target of Opportunity Handling*

  - – *Burst Alert Handling*

  - – *Solid State Recorder Management*

- ▶ *Off-line Analysis*

  - – *Level 0*

  - – *Trending and Data Analysis*

  - – *As-Flown Timeline*

Ground System Architecture

GPS

GPS Timing & Position Data

TLM: S-band @ 1,2,4,8 kbps
CMD: S-band @ .25, 4 kbps

TDRS

TLM: S-band @ 2.5 Mbps
X-band @ 20 Mbps
CMD: S-band @ 2 kbps

GLAST

Ground Stations
Malindi, USN

RT HK Telemetry
Command Data
Sci & HK Data Dumps

Alerts/Alarms
RT HK Telemetry
Command Data

White Sands Complex

Mission Operations Center
GSFC

T&C Data Flows

Launch Site
KSC

Orbit Support

FDF
GSFC

Spacecraft I&T Facility
Spectrum Astro

Test & Sim Data
Sustaining Eng Data

Level 0 Data
Observing Plan
TOO Requests
As-Flown Timeline

Burst Msgs

Level 0 Data
Contingency Cmd
As-Flown Timeline

Level 0 Data
Contingency Cmd
As-Flown Timeline
Burst Msgs

Gamma-Ray Coordinates Network
GSFC

GLAST Science Support Center
GSFC

Level 1/2 Data
LAT Commands/Loads

Level 1/2 Data
GBM Commands/Loads

LAT Instrument Ops Center
SLAC

GBM Instrument Ops Center
MSFC

GLAST Data

Science Products

Archive Data

Mirror Site
Italy

Science Community

HEASARC
GSFC

Version: 7/10/03

4 - 3

Operations Overview: Week in the Life

▶ **Nominal MOC Operations Highly Automated (approach based on IMAGE, MAP, SMEX, Swift, etc. heritage)**

– *Single 8x5 Staffed Shift (On-call FOT outside normal 8x5 shift)*

– *Manual Activities (FOT)*

• *Mission Activity Planning and Scheduling, GN and SN Scheduling, Real-Time commanding, Telemetry Monitoring, Spacecraft and Instrument FSW Loads, MOC Maintenance (PDB, Software, or Hardware)*

– *Automated Activities (Software, Scripts)*

• *Off-Shift Pass execution, Data Processing, Telemetry Monitoring, Data Archiving, Trending, Event Logging, Alarm Recognition, Automated Personnel Notification*

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
8AM	- R/T command opportunity	- R/T command opportunity - Mission Planning and Scheduling	- R/T command opportunity - Uplink new ATS	- R/T command opportunity	- R/T command opportunity	*On-Call*	
5PM	- L0 processing - Data trending	- L0 processing - Data trending	- L0 processing - Data trending	- L0 processing - Data trending	- L0 processing - Data trending	- L0 processing - Data trending	

Operations Overview

► **MOC/FOT provides "front-line" support for spacecraft and instrument health and safety and performance monitoring/trending**

– *Instrument performance analysis/monitoring primarily responsibility of respective IOC's*

– *Spectrum Astro provides spacecraft sustaining engineering as "back-up" to FOT*

► **Ground stations for routine commanding and high rate data dumps**

– *Malindi, Kenya and Universal Space Network (South Point, Hawaii)*

– *Perform RS-decoding, report statistics to MOC, sorts data by virtual channel, and time stamps data at the frame level*

  • *2.5 Mbps S-band: Real-time telemetry (HK and Burst Alerts), Memory Dumps, Housekeeping Data Dumps (SSR)*

  • *20 Mbps X-band: Science Data Dumps (SSR)*

  • *Approximately 5-6 contacts per day*

– *High-rate S-band and X-band data received post-pass within 6 (TBR) hours of end of pass*

► **Space Network (TDRS, WSC, DAS, SWSI)**

– *Provides continuous MA Demand Access (DAS) service for Burst Alerts, low rate HK, and Safe Mode Notifications*

– *Provides schedulable MA and SSA service for ToO support, higher rate HK, flight software updates*

Operations Overview

- **Observatory primarily operates in Survey Mode for first year**

  – *With occasional requests for special targeting or autonomous repointing*

- **After first year, science operations also driven by Guest Investigator Program and autonomous repointing**

  – *Survey mode will still predominate during later years*

  – *GSSC serves as central collection point and coordinator for science/mission planning and scheduling, providing an integrated science timeline to MOC*

- **LAT and GBM detect Gamma-Ray Bursts and generate Burst Alerts that are sent to the ground via the continuously available SN/TDRSS Demand Access Service (DAS)**

  – *MOC forwards the burst alerts automatically to science community via the BAP/GCN*

Operations Overview

▶ **Orbit determination automated due to use of on-board GPS**

– *MOC receives orbit data in telemetry and propagates as needed for ground station and SN scheduling*

– *MOC provides spacecraft with TDRS ephemeris data as needed*

▶ **Implementing additional orbit determination methods to augment the on-board GPS capability**

– *Used to help verify the GPS capability during L&EO and for contingencies if GPS capability is ever unavailable*

– *Method 1: NORAD-generated Two-Line Elements (TLE's), like Swift*

  • *TLE's should give us accuracy to 1-5 km*

  • *Processed by MOC and FDF (if needed)*

– *Method 2: Differenced One-Way Doppler (DOWD) with TDRSS*

  • *Spacecraft telemetry received by two TDRS satellites*

  • *FDF able to generate orbit solution using this data, and provides orbit products to the MOC*

  • *On UARS, DOWD provided orbit position accuracy to <0.5 km*

– *Neither method impacts spacecraft design nor science data collection*

Operations Overview

▶ ***Majority of science and mission operations pre-planned and executed from stored command loads***

 – *Frequency of stored command loads is expected to be weekly, with nominally no uplink of commands over the weekends*

 – *System does support late changes to on-board schedule (after load has been uplinked)*

▶ ***Project Scientist able to quickly retarget observatory via Target of Opportunity (ToO) Requests***

 – *Expected approximately once per month, but higher frequencies can be supported if science dictates*

 – *ToO's handled by GSSC and MOC*

 – *Turnaround requirement < 6 hours*

   • *From point where Project Scientist gives GSSC go-ahead to when ToO commands hit spacecraft*

Mission Planning and Command Generation
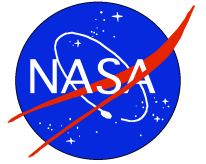
▶ *IOC's develop the commands/timelines for their instruments and send to GSSC*

▶ *Inputs from IOCs are sent to GSSC*

- *Includes FSW loads, calibration activities, instrument adjustments, etc.*

- *GSSC checks for impact to existing timelines and notifies IOC if there is a problem*

▶ *GSSC integrates Guest Investigator-driven observations, IOC commands/timelines, and weekly schedule received from MOC/FOT*

▶ *GSSC provides MOC with integrated science timeline*

- *List of activities and/or commands to be accomplished on observatory*

- *Nominally covers a period of 7 days*
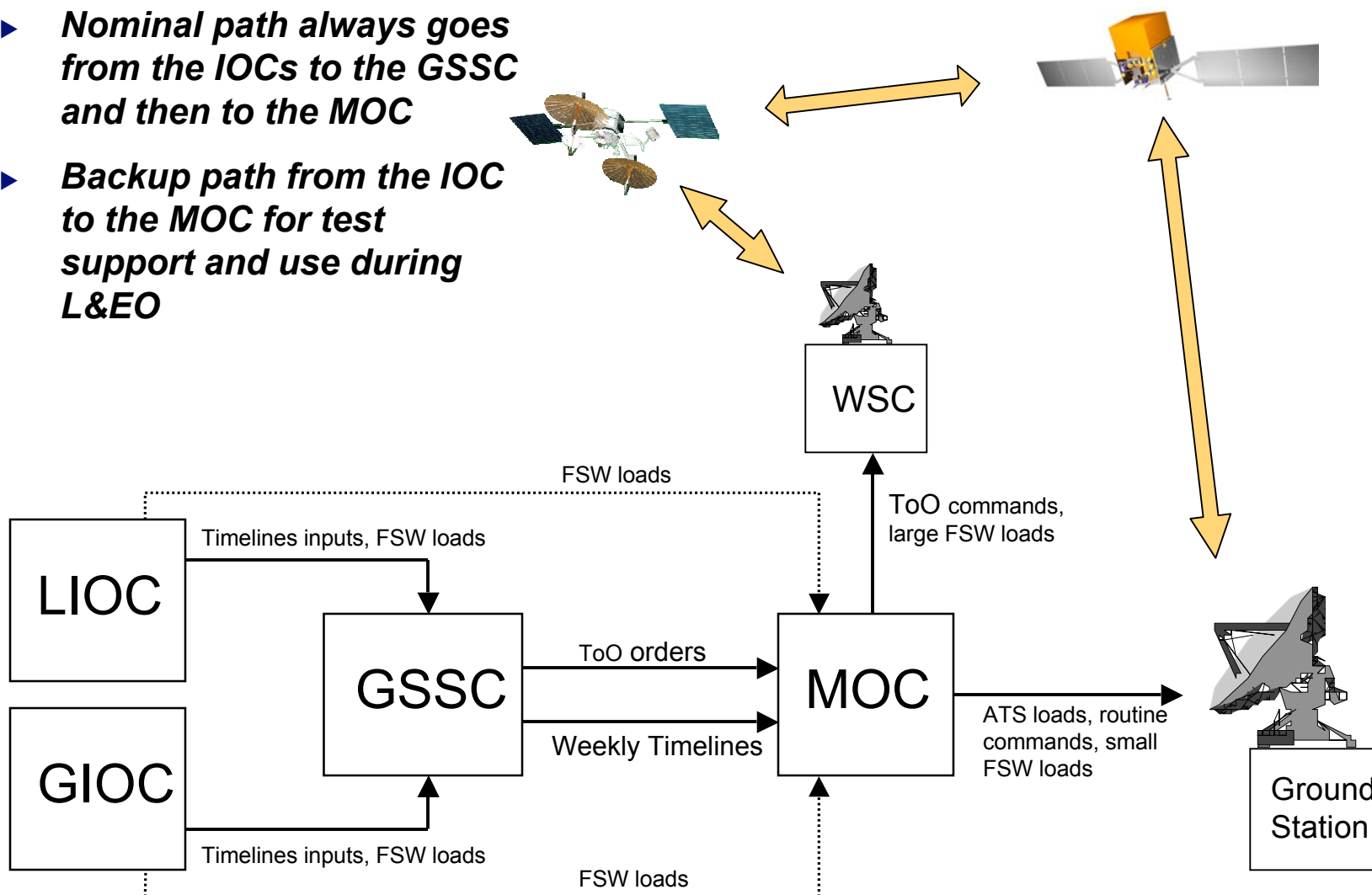
Mission Planning and Command Generation

- ▶ **MOC integrates the science timeline received from GSSC with ground system commands such as contact schedule, ephemeris updates, etc.**

  - *MOC receives timelines from GSSC and MOC checks*
    - *Constraint checking, invalid commands or missing sub-mnemonics, out of range parameters, command frequency limit violations, etc.*

  - *Absolute Time Sequence (ATS) load created and uplinked to non-active ATS buffer for later execution*

  - *ATS contents are absolute time tagged commands such as instrument commands, transmitter on/off sequences, recorder playback commands,*

- ▶ **GSSC also forwards instrument FSW tables provided by the IOCs to the MOC for uplink**

  - *Uplinked as per instructions given with each table/load*
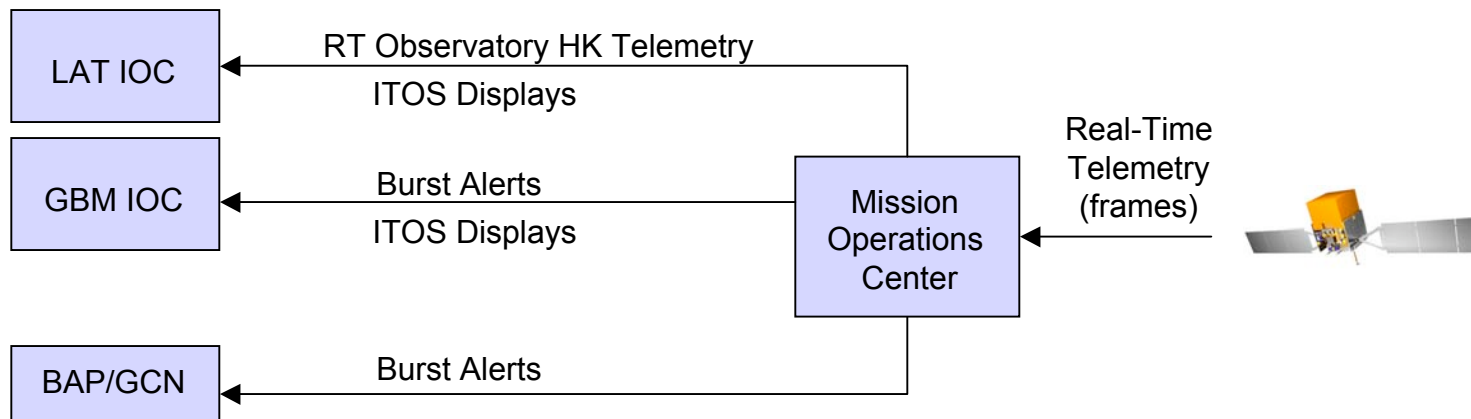
Mission Planning and Command Generation
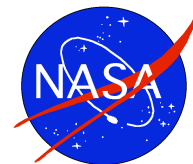
- ► *Nominal path always goes from the IOCs to the GSSC and then to the MOC*

- ► *Backup path from the IOC to the MOC for test support and use during L&EO*

WSC

FSW loads

ToO commands, large FSW loads

Timelines inputs, FSW loads

LIOC

GSSC

ToO orders

MOC

ATS loads, routine commands, small FSW loads

Weekly Timelines

GIOC

Timelines inputs, FSW loads

FSW loads

Ground Station

Real-Time Telemetry

▶ *Autonomous downlink of burst alerts or safe-mode alerts using Space Network Demand Access System*

▶ *Space Network and ground stations forwards selected Virtual Channels (VC's) to MOC in real-time (frame data)*

    – *Observatory HK telemetry, Burst Alerts, Safe-mode alerts, and Memory Dumps*

    – *All VC's stored at station and forwarded to MOC post-contact*

▶ *MOC performs traditional real-time processing on incoming telemetry*

    – *Extract packets, decommutate and display HK data, generate/display event messages and alarms, perform command verification*

▶ *Forward instrument packets in real-time to the LAT IOC to assist in instrument monitoring (but not critical)*

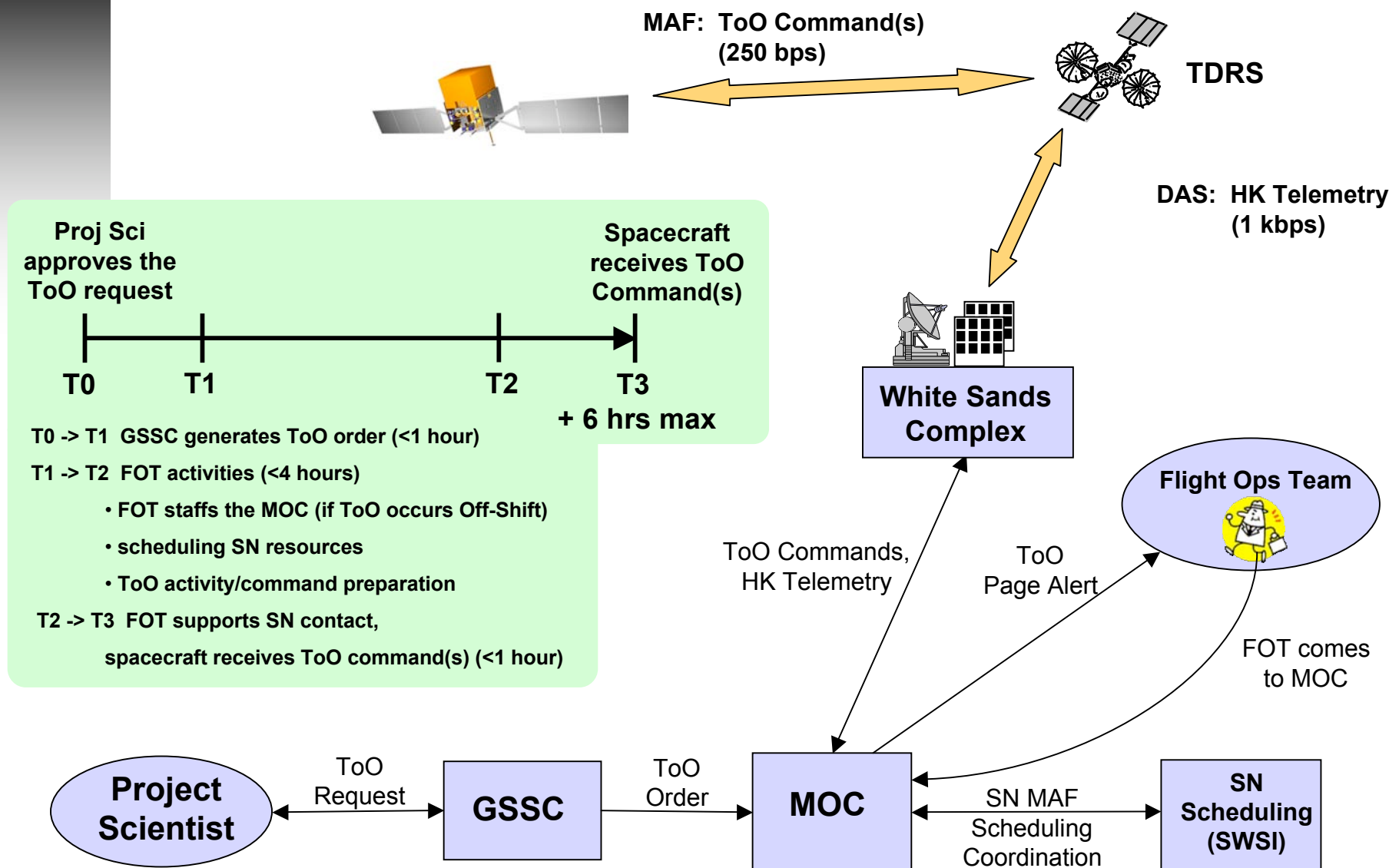   – *IOC's can also call up MOC ITOS displays over the Internet (MOC Web server)*

LAT IOC	← RT Observatory HK Telemetry / ITOS Displays	
GBM IOC	← Burst Alerts / ITOS Displays	Mission Operations Center	← Real-Time Telemetry (frames)
BAP/GCN	← Burst Alerts	

Target of Opportunity Handling

▸ *ToO Request can result from an approved Guest Investigator proposal or an interesting celestial event*

▸ *GSSC analyzes the ToO Request (feasibility, impact on schedule) and advises the Project Scientist accordingly*

▸ *Project Scientist approves a ToO Request*

▸ *Upon receiving authorization to proceed with the ToO, the GSSC constructs the ToO Order and forwards to the MOC*

▸ *MOC recognizes ToO Order and notifies appropriate FOT personnel for action*

– *FOT processes ToO Order*

– *Works with SN to schedule a forward link via TDRSS*

– *MOC transmits the ToO commands to the spacecraft as soon as the SN forward link is available*

– *FOT monitors telemetry to verify ToO is being acted upon if done in near real time – otherwise FOT analyzes after-the-fact*

– *Observatory autonomously returns to on-board observing schedule at completion of the ToO*

Target of Opportunity Handling

MAF: ToO Command(s)
(250 bps)

TDRS

DAS: HK Telemetry
(1 kbps)

Proj Sci approves the ToO request

Spacecraft receives ToO Command(s)

T0 —— T1 —————————— T2 —— T3
+ 6 hrs max

T0 -> T1 GSSC generates ToO order (<1 hour)

T1 -> T2 FOT activities (<4 hours)
- FOT staffs the MOC (if ToO occurs Off-Shift)
- scheduling SN resources
- ToO activity/command preparation

T2 -> T3 FOT supports SN contact,
spacecraft receives ToO command(s) (<1 hour)

White Sands Complex

Flight Ops Team

ToO Commands, HK Telemetry

ToO Page Alert

FOT comes to MOC

Project Scientist ← ToO Request → **GSSC** → ToO Order → **MOC** ← SN MAF Scheduling Coordination → **SN Scheduling (SWSI)**
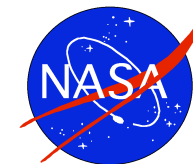
Burst Alert Handling

▶ ***LAT and/or GBM detect GRB and determine that it warrants sending a Burst Alert to the ground***

  – *Instruments generate Burst Alert (not spacecraft)*

  – *Spacecraft initiates link with TDRSS/DAS, and sends Burst Alert as received from instruments*

    • *Alerts go through ground station if already in a contact with MOC*

  – *If the GRB warrants, LAT requests spacecraft to slew to the target (referred to as an Autonomous Repoint)*

▶ ***WSC forwards messages to MOC, which pulls out Burst Alert packets and forwards to:***

  – *Burst Alert Processor(s) (BAP) for distribution to the science community via Gamma-Ray Coordinates Network (GCN)*

  – *BAP(s) co-located with the MOC, which perform additional processing on the messages*

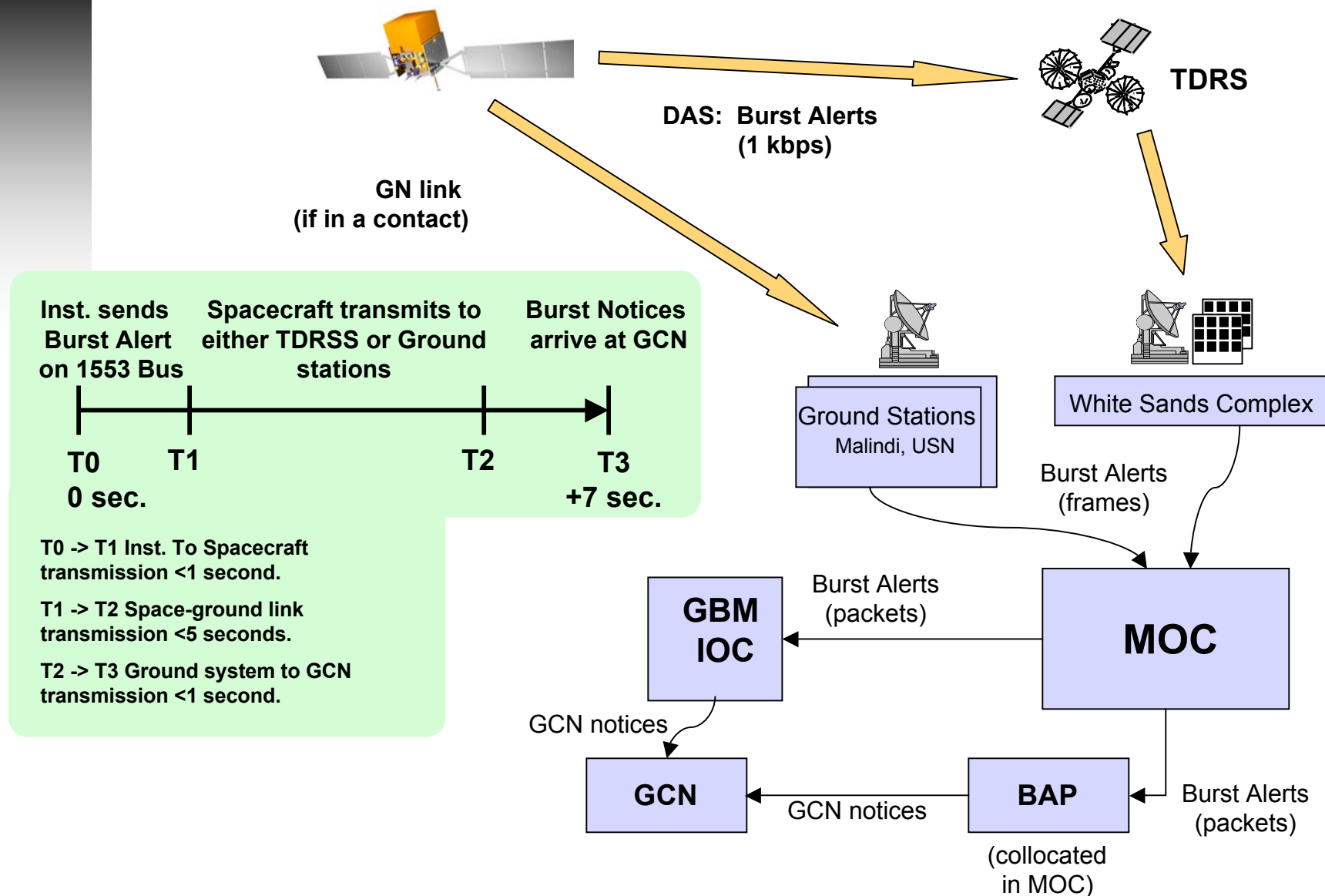   • *BAP sends to the GCN once processing completed*

Burst Alert Handling (cont.)

▶ ***Burst Alerts are sent from a single location i.e. the MOC***

- – *Alerts captured by multiple locations (SN and GN)*

- – *Prefer to centralize Burst Alert frame processing*

- – *BAP within MOC needs the messages for additional processing*

- – *Directly to the GBM IOC for additional processing*

- – *BAP also sends to the GCN*

- – *Above characteristics led to GLAST approach vs. Swift approach (direct from WSC to GCN)*

Burst Alert Handling (cont.)

TDRS

DAS: Burst Alerts
(1 kbps)

GN link
(if in a contact)

Inst. sends
Burst Alert
on 1553 Bus

Spacecraft transmits to
either TDRSS or Ground
stations

Burst Notices
arrive at GCN

T0   T1   T2   T3
0 sec.   +7 sec.

T0 -> T1 Inst. To Spacecraft
transmission <1 second.

T1 -> T2 Space-ground link
transmission <5 seconds.

T2 -> T3 Ground system to GCN
transmission <1 second.

Ground Stations
Malindi, USN

White Sands Complex

Burst Alerts
(frames)

GBM
IOC

Burst Alerts
(packets)

MOC

GCN notices

GCN

GCN notices

BAP

(collocated
in MOC)

Burst Alerts
(packets)

Solid State Recorder Management

- **Two distinct types of on-board data stored in recorder: Science and Housekeeping**

  - *Stored in two separate partitions (i.e., two virtual recorders)*

  - *Dumped separately, but simultaneously*

    - *Science on X-band, Housekeeping on S-band*
    - *Cannot dump LAT or GBM Science data individually – must dump both*

- **SSR holds 96 Gbits of data, and 36-hours storage is ~ 52 Gbits**

- **At 20 Mbps, require a minimum of 4 contacts per day (avg 9 minutes per contact) to ensure adequate downlink time**

  - *Operations will plan for 5-6 contacts to account for anomalies*

- **FOT will automate dumps via stored commands**

- **During all contacts, MOC automatically monitors RF-related statistics from ground station and SSR pointers in Housekeeping telemetry**

  - *FOT notified for problems detected that require operator interaction*

- **MOC makes assessment of data completeness once frame files received from the ground stations**

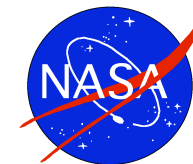 - *Again, operators notified if significant problems detected*
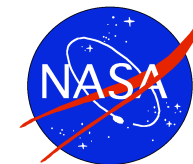
Ground Station Contact Profile

► **30 day contact profile for with two sites:**

– *USN-Hawaii and Malindi, Kenya*

– *Minimum 3 minutes duration*

– *Minimum five degrees elevation*

	Contacts in 30 Days	Avg Per Day	Mean Length: Minutes	Contact Grouping	Time Between Contacts: Gap 1: Hours	Time Between Contacts: Gap 2: Hours
Tracking Site						
USN: Hawaii	225	7.3	9	All Contacts in one group	13	N/A
Malindi	201	6.5	8	Two groups of 3 or 4 contacts	8.5	6

Site and Times	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
USN - Hawaii									●		●		●		●		●	●		●		●		
Malindi								●		●		●						●		●		●		●

SSR Dump Profile (Science Data)

**SSR capacity: All contact opportunities, 3 minute minimum duration, 5° elevation**
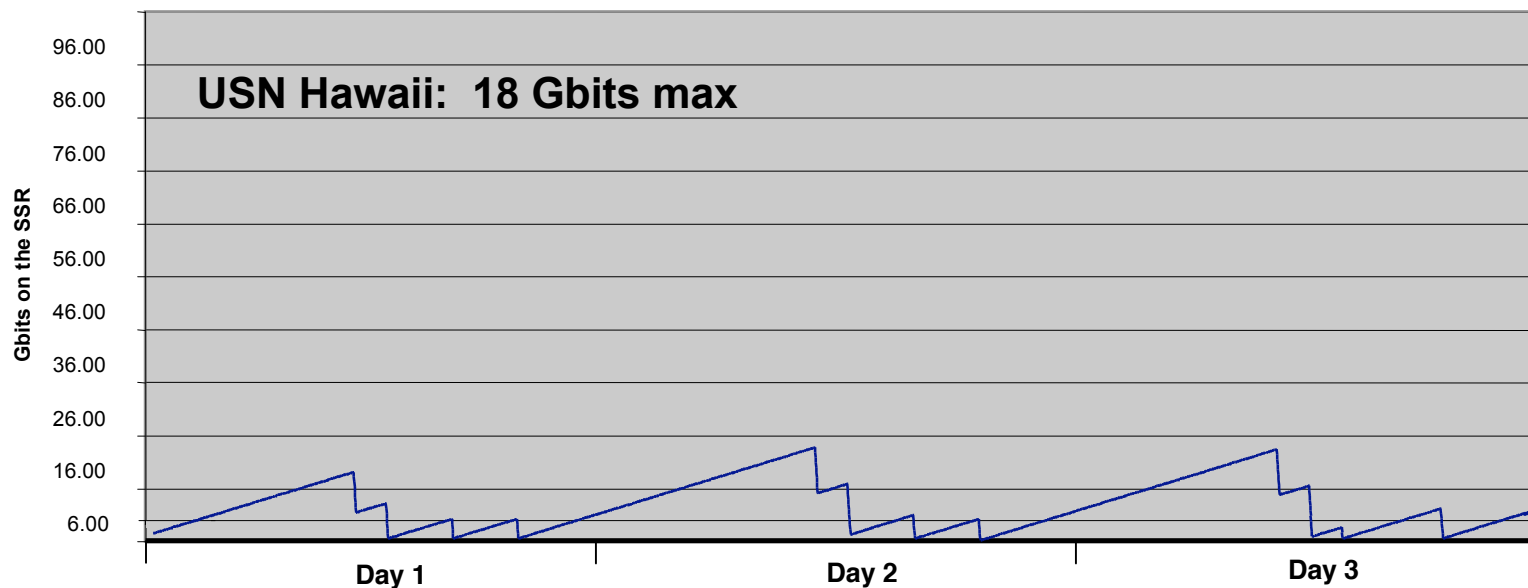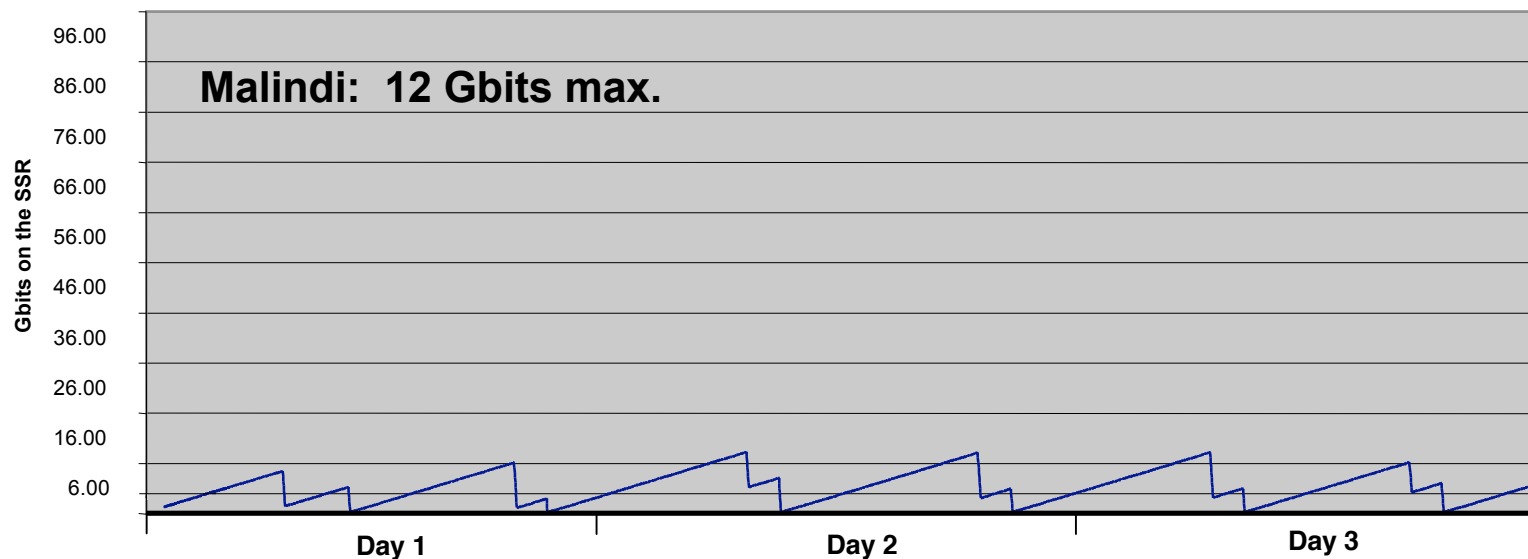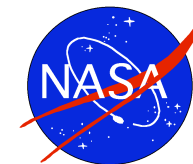
Data Processing

▶ ***Level 0 processing performed on a per-pass basis***

– *Ground Station records frame-level data during each contact, sorts by VCID, and automatically transfers to MOC post-contact*

– *MOC automatically begins Level-0 processing on files as they are received from the ground station*

- *extraction of packets from frames, Reed-Solomon (RS) decoding, time ordering of data, removal of duplicate packets, and quality and accounting information.*

- *Upon completion, files automatically sent to IOC's and GSSC*

– *IOC's generate Level 1 and 2 data products and provide to GSSC*

- *GSSC provides products to science community*

- *GSSC provides Level 1,2 data to Mirror Site (Italy) and performs selected science data data processing*
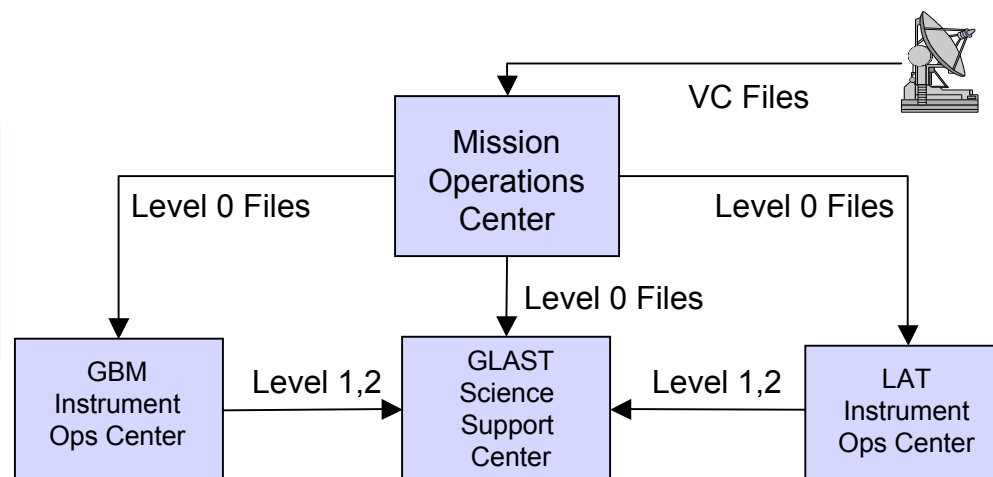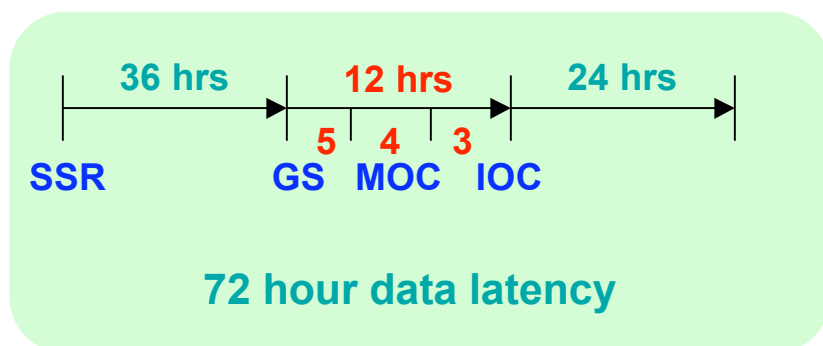
Off-line Analysis

- ▶ **MOC Data Trending and Analysis**

  - Selected spacecraft and instrument housekeeping parameters are ingested into a database

  - System provides off-line trending, analysis, and plotting capabilities

  - System provides remote access to users such as Spectrum Astro or IOC personnel

- ▶ **IOC Data Trending and Analysis**

  - For monitoring the status and quality of the science data, including performing instrument trend analysis and plotting

  - For monitoring health & status, performing daily trend analysis, and anomaly investigation

- ▶ **As-Flown Timeline**

  - Since GLAST has the ability to autonomously deviate from the pre-planned science timeline it is necessary to track deviations or unplanned activities such as Auto-Repoint targets or ToOs.

  - MOC generates an As-Flown Timeline based on what observatory actually did and provides to GSSC and IOCs

  - Created entirely from observatory housekeeping telemetry

  - Intended to be a high level record of the actual observatory observations